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RADIUM

and all about it.

BY

S. BOTTONE.

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RADIUM,

AND ALL ABOUT IT.

BY

S. R. BOTTONE,

AUTHOR OF "RADIOGRAPHY," "WIRELESS TELEGRAPHY,"
"ELECTRICAL INSTRUMENT MAKING," ETC.

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INDEX.

The figures refer to the sections, NOT *to the pages.*

RADIUM,

AND ALL ABOUT IT.

CHAPTER I.

Historical Notes.

1. Perhaps no subject has awakened so much interest in the mind of the general public as the discovery of radium. This has been partly due to its excessive rarity and consequent high price; partly to the suggestions made by several medical men of high repute of the possibility of its being successfully used in the treatment of cancer, sarcoma, lupus, and kindred diseases; and yet more by the extraordinary physical properties possessed by this new substance—properties which at first glance seem destined to revolutionise many of our accepted views of the conditions in which matter, and especially the so-called "elements," exist.

2. The discovery of radium was by no means accidental; but the result of following out and tracing up the source of certain phenomena noticed by observant experimenters. Briefly these phenomena were: first, the power which certain bodies acquired, after having been exposed to light, of throwing off radiations that would discharge negatively electrified bodies (observed by Elster and Geitel in 1889); second, the property which certain rays set up by an electric discharge in a high vacuum, although invisible to the human eye, possessed of traversing many substances, opaque to *light*, and of affecting a photographic plate after thus passing. This observation was due to Röntgen in 1895, though Lenard appears to have noticed some of these effects at a slightly earlier date. These rays were termed by Röntgen—"X" rays; third, M. Henry, in 1896, while experimenting with a view to ascertain whether such rays were given off in any other circumstances, ascertained that zinc sulphide (long known as possessing the faculty of phosphorescing for a considerable time after exposure to light) is also capable, after such exposure, of emitting non-luminous rays, which, although in-

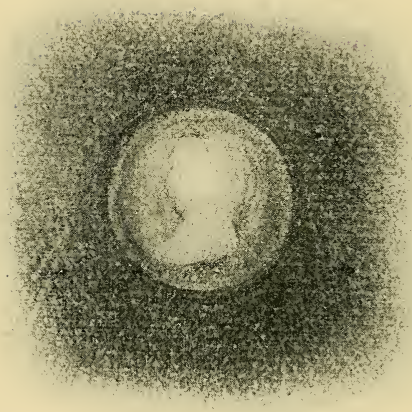

Fig 1.

visible to the eye, are endowed with the power, like the Röntgen rays, of traversing several opaque bodies—*e.g.*, folds of black paper, and subsequently of impressing an image on a sensitive photographic plate. Close upon this followed the observation of Professor Henri Becquerel, that the potassio sulphate of uranium was gifted with the same power. Accidentally he discovered that, in the case of uranium salts, a previous exposure to sunlight was not essential to the evolution of these dark rays; in fact, even if an uranium salt be crystallised out of its solution *in the dark*, and kept there, it still possessed the power of emitting these rays, and therefore of affecting a photographic plate. These "Becquerel" dark rays can traverse wood and the lighter metals. By placing an aluminium medal on a black paper envelope, covering this with a card, over which were sprinkled crystals of the double sulphate of potassium and uranium that had never been exposed to light, Becquerel was able to obtain a radiograph similar to that shown in our Fig. 1. We have seen that Elster and Geitel had observed the fact that certain substances that had been exposed to light emitted radiations that would discharge negatively electrified bodies: in common with X rays. Becquerel noticed the same power in the rays bearing his name.

3. Subjecting these uranium salts to careful examination, Sir William Crookes lighted upon the discovery that these rays did not proceed from the uranium itself, but from some trace of impurity contained in the salt. By repeated crystallisations, setting on one side the crystals which formed more readily, and, on the other, the ones that were slower in formation, he was able to separate two distinct batches of crystals; one of which possessed in a marked degree the power of emitting these rays, or being "radio-active," while the other was devoid of any such power. The next step to advance our knowledge of the radio-active basis of this salt was taken by Madame Curie, working in conjunction with her husband. Madame Sklodowska Curie is of Polish descent, and was born at Warsaw in 1867. Her early education was obtained in that city. Going to Paris in 1891, she there continued her studies at the University, where in time she received her "master's" degree in physics and mathe-

matics. In 1895 she married Professor Pierre Curie, who worthily fills the chair of physics in the University of Paris. The following year she passed an examination permitting her to become a candidate for a professorship in a girls' college, and in 1900 she was appointed Professor of Physics to the State Normal School for Women at Sèvres. She has written several works on physical subjects, and expects shortly to take her doctor's degree at Paris; this being the highest attainable in France. She took up as the subject of thesis for her doctorate, that of radio-activity, wherein she displayed so much ability and thorough grasp of the matter, that the Austrian Government, acting under the advice of Professor Suess, assisted Madame Curie by placing at her disposal some tons of the residue, or "tailings," of the ore from which uranium had already been extracted, and which was therefore richer in the really radio-active constituent.

4. At this point Professor Curie took up the subject in conjunction with his wife, and in 1901, under his direction, were erected refining works at Ivry, outside the walls of Paris, near the old Ivry Cemetery, where

tons of the refuse of the Bohemian pitch-blende, from which the uranium had previously been removed, have been treated. This refuse presents the appearance of a lumpy reddish powder. The result of their researches has been the discovery of at least three new elements—viz., *radium*, *polonium*, and *actinium*—all gifted in a very high degree with radio-active properties. Of these radium is the body which occurs in the greatest quantity in this ore (though even this is very minute, since eight tons of residues yielded only fifteen grains (one gramme) of fairly pure radium chloride), it is the body which has received most attention. As to *polonium*, it is contained in the ore in such minute quantities only, that Professor Markwald could extract but $\frac{15}{100}$ of a grain of polonium from two tons of the refuse uranium ore.

CHAPTER II.

Mode of Detection and Extraction.

5. Radium, in the metallic or pure state, has not yet been isolated. Although, as Professor Curie has stated, this would probably present no great difficulty, by treating its chloride with potassium or sodium in the usual manner, so as to extract therefrom its chlorine, yet, as a matter of fact, we know this body only in combination with chlorine, as *chloride*, with bromine, as *bromide*, or, with the radical of nitric acid, as *nitrate*. From considerations based on its atomic weight, its spectrum, and the crystalline form of its compounds, there is not much doubt but that it is a metal belonging to the calcium, strontium, and barium group, similar to magnesium in appearance, but much heavier. In the preparation of radium chloride, as at present carried on by the Curies, the pitchblende, of which the percentage composition is, Uranium 81·5, Lead 4, Iron 0·5, Barium, Calcium, along with minute traces of other elements, make

up the 100 parts. Of these "other elements," radium constitutes about $\frac{1}{1600}$ part. The mode of treatment, after the uranium has been extracted, is to fuse the residue with carbonate of soda, to dissolve in hydrochloric acid, and begin by precipitating the lead and other metals of that class by the aid of hydrogen sulphide (sulphuretted hydrogen). This treatment removes the precipitable metals, as copper, iron, zinc, and lead. What remains in solution is principally a mixture of barium chloride, along with the chlorides of radium, polonium, actinium, etc. Taking advantage of the fact that the radium chloride crystallises more readily than the corresponding barium salt, it is then possible, by repeated "fractional" crystallisations, to separate the radium chloride from its accompanying barium chloride. For instance, say that from one ton of residues we were able to obtain sixteen pounds of crude barium chloride crystals. On testing a portion of these sixteen pounds, owing to the minute trace of radium they contained, we should find that its radioactivity, as compared to that of uranium, would be, say, sixty times as strong. Now, on redissolving these crystals in water, and setting the solution aside to recrystallise, and collecting the crystals that are the first to form, this second crop of crystals is found to be five times more powerfully radio-active than the first crop. By repeating this process of dissolving, crystallising, and collecting the first crystals, the richness of the crystals in radium chloride (and consequently their radio-activity) increases five times with each operation; so that after a long series of such fractional crystallisations, it is possible to obtain crystals possessing 1,500,000 more radio-activity than uranium. This is practically pure radium chloride. In appearance it is not unlike common salt; glowing feebly in the dark, somewhat like stale fish. In practice, on a fairly large scale, the Curies have been able to obtain from eight tons of uranium ore residues, about one gramme (fifteen grains) of the pure radium chloride. This brings the price up to about £25 5*s*. per grain, or, say, 3,000 times the price of gold. More recently, the German chemist, Giesel, has succeeded in extracting radium bromide by a modification of the above process in a trifle larger quantity—namely, four grains from one ton of residues.

6. To detect the presence of radium, or to put it more exactly, of a radio-active element, in any suspected mineral, advantage is taken of one or more of the following properties, with which radium is specially endowed. The first is the power possessed by its emanations, even though utterly invisible to the eye, of converting the air through which they are disseminated into a conductor of electricity. Suppose we had a charged Bennett's gold leaf electroscope in a fairly dry atmosphere, we should have the gold leaves divergent, as shown in our Fig. 2, and this divergence would, in ordinary circumstances, continue for some considerable time, the leaves collapsing only gradually as the charge was dissipated. But, on the approach of a mineral or salt containing any appreciable amount of radium, the leaves would quickly collapse, as shown in our Fig. 3, proportionately more quickly

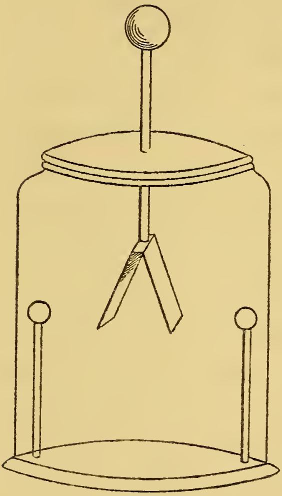

Fig. 2.

as the body subjected to this trial were richer in radium, and consequently rendered the circumambient air more conductive of electricity. It is by this means that Professor and Madame Curie tested their samples for richness in radio-active matter, and gauged the degree of concentration, or purity, to which they had brought the radium chloride. The second property, which is not nearly so delicate in its indications, is that of affecting a photographic sensitive plate, shielded from light by being enclosed in an opaque (but not metallic) envelope. A third property, which, however, is only observable when the radium constitutes a considerable portion of the body under examination, is that of causing other bodies (such as, for example, zinc sulphide) placed

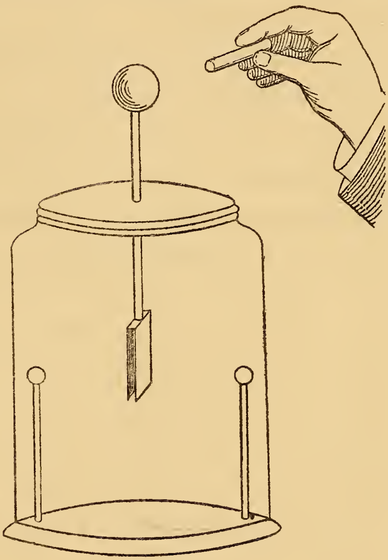

FIG. 3.

in its vicinity to *phosphoresce*, more or less brilliantly, in proportion to the richness of the mineral in radium. When the radium salt is nearly pure, not only will it confer the power of glowing on such substances as calcium sulphide, barium platino-cyanide, barium sulphide, and similar well-known phosphorescent bodies, but all articles placed within reasonable distance of it, say, within the range of its emanations, become phosphorescent. Even the hands and clothes of the operator become thus gifted with the power of glowing in the dark.

CHAPTER III.

Properties of Radium.

7. Having thus briefly glanced at the causes which led up to the discovery and thereupon the extraction of radium, we are in a position to study its most remarkable properties, as noted by different scientific observers. It must be borne in mind that radium, in the uncombined state, has not, up to the present time, been isolated; and that the compounds hitherto chiefly studied—*viz.*, its chloride, its bromide, and its nitrate—have been obtained in such small quantities only that it is calculated that, in the whole of Europe, including Germany and France, not more than $2\frac{1}{2}$ grammes (say, $37\frac{1}{2}$ grains), or a trifle over half-a-drachm, of these salts have been prepared and exist in a pure form. Hence, our knowledge of the behaviour of *pure* radium is absolutely *nil*, and that of its salts very meagre and uncertain, owing to the minute quantities on which scientists have been compelled to

experiment. But the results obtained even in these unfavourable circumstances are most interesting, and would appear, under many aspects, to be such as will revolutionise our previous views of the behaviour and constitution of elemental matter.

8. The appearance of the purified radium chloride, as obtained from its solutions by repeated crystallisations, so as to free it as far as possible from the accompanying barium salt, is very similar to ordinary table salt (sodium chloride), slightly yellowish in tint, the crystals belonging to the "regular" system. The salt is heavy, and does not appear to be deliquescent, as are the corresponding calcium and barium compounds. As the result of several experiments made by the Curies, it would appear that the atomic weight of radium itself, as calculated from its compounds, is 225, hydrogen being taken as unity. Messrs. Runge and Precht, from considerations based upon an examination of the spectrum of radium, give its atomic weight as 257·8. Presuming that radium belongs to the calcium-barium-strontium group of elements (as would appear probable from the character of the spectrum), these num-

bers will require verification, as they do not agree well with Mendelëeff's periodic law; which we shall notice farther on.

9. The most striking properties of the radium salts are certainly those of continuously emitting a feeble light, visible in the dark, which has been likened to that given off by decaying fish, and of evolving heat. Not only have these radium salts these properties, but, by virtue of emanations continuously given off, they are able to impart the phosphorescent power, in some instances in an exalted degree, to all other bodies placed within their range, notably to zinc blende (sulphide of zinc). Besides this, heat rays are continuously being emitted, so that the temperature of a piece of radium chloride is always about 1·5° Centigrade above that of surrounding bodies. These emanations were at first thought to go on indefinitely, without any loss or decrease on the part of the radium salt itself. We shall learn from what follows that this view requires modification. Still, there is no doubt that the loss sustained by the radium whilst thus setting up these phenomena is infinitesimally small, so small, in fact, as to defy measure-

ment when operating on the very small quantities of material up to the present placed at our disposition.

10. We have already noticed that all the radio-active bodies yet known possess the faculty of emitting invisible rays, which rays can traverse visually opaque bodies, and impress an image on the photographic plate. This property is largely shared by the radium salts. But the effects of these radiations or emanations are not confined to their action on photographic plates. They have a powerful influence on the animal organism. Professor Becquerel carried in his waistcoat pocket, while journeying to London to give a lecture, a small sealed tube containing a few milligrammes* of radium salt. Nothing happened at the time, but after about a fortnight he observed that the flesh under his pocket was beginning to redden. The skin then fell away, leaving a deep and painful sore, which formed there and remained for weeks before healing. One peculiarity of these radium sores is, that they do not give evidence of their existence until some considerable time after exposure to the radium emanations. It would appear

* A milligramme is about $\frac{15}{1000}$ of a grain.

that these injurious rays, or emanations, are, to a great extent, impeded by the interposition of a screen of metallic lead, so that a tube containing radium,* if wrapped in sheet lead, may be handled with impunity. If a tube containing radium be wrapped in several folds of paper, and laid against either of the closed eyelids, a sensation of diffused light is immediately perceived. This effect is produced, not by the eye really *seeing* any light proceeding from the radium itself, but as a result of a kind of phcsphorescence set up by the radiations, or emanations, therefrom in the liquid and other portions of the eye itself. That this is really the case may be shown by keeping the eye still closed and placing the tube on the temples or cranium itself, when the light will again be perceptible, though in lesser degree. Such an experiment must not be long continued, otherwise injury to the eyesight, or even blindness, might follow. On the other hand, it has been suggested by Dr. Emile Javal, a distinguished French physician, who himself is blind, that this peculiar property of radium may itself be a valuable means of

* Unless otherwise specified by "radium," one of the radium salts is understood

diagnosing the state of the retina in cases of cataract, since, if the patient *can* see the radium light, then the retina is intact, and an operation will lead to successful results; whereas, if no light be perceptible, the retina is injured, and sight will not be restored by operating. Professor Curie, who naturally has had much to do with handling different radium salts, suffered very considerably from this disintegrating effect that strong radium emanations exert upon animal organisms. After his lecture at the Royal Institution in London (which we reproduce elsewhere) he had bad sores on his forearm, while his hands were much peeled from too much exposure to the radiations, or emanations. For several days he was not able to dress without assistance.

11. Here we must point out that although we have used the words "radiations" and "emanations" indiscriminately, they are really quite distinct. It has recently been shown, both by Professor Curie and by Miss Gates, that the "emanations" consist really of some matter in a gaseous state capable of diffusion, like other gases, through air and porous substances, as paper, etc., but unable to pass through thin sheets of mica. From

their "diffusion rate," it has been shown that they behave like heavy gases, having a molecular weight exceeding one hundred times that of hydrogen. Like gases in general, these emanations can be condensed from other gases with which they may be mixed, by the action of extreme cold. The radium emanations begin to condense at a temperature of -150° Cent. Besides this gaseous emanation there appears to be another, capable of being dissolved by some acids and not by others. According to Miss Gates, it is to this solid "emanation" that the power which radium (in common with thorium) has of exciting radio-activity in other bodies is due. It would appear that this radio-active matter is deposited upon such excited bodies in such minute quantity as to be invisible and imponderable. It would appear to have definite chemical properties. It can be dissolved by certain acids, it is capable of being volatilised at a white heat, and is redeposited on the surface of cold bodies in its neighbourhood, endowing them, in their turn, with the power of radio-activity. The exact nature of these two emanations we are not yet in a position to state with any degree of certainty: according to the experiments of Professor Rutherford, it is highly probable that the gaseous form is *helium*, or, at least, one of its compounds. The solid emanation has not yet been obtained in sufficient quantity to admit of its constitution being ascertained.

12. Of these true *radiations*, not reckoning that of *heat*, which may be a result of intra-atomic movement or even disintegration of the atoms, we are able to distinguish three—namely, the α, the β, and the γ rays. The α rays have not much penetrative power; in fact, they are stopped by a layer of air a few millimetres thick (one millimetre equals $\frac{1}{25}$ of an inch); by a sheet of note paper, or by a thin sheet of aluminium. These α rays appear to carry with them positive charges of electricity. The reason for believing this, is because these rays are found to be deviable by a powerful magnet, in the same direction as particles carrying a positive charge are deflected by the magnet. It was originally thought that these α rays were undeviable; but by placing some radium at a very small distance from a strip of photographic plate, the whole being inserted in a saw-cut in a block of lead, and using an extremely powerful electro-

magnet, Professor Rutherford has been able to prove their deflectability, by causing the image of the rays to impress themselves to the right, or to the left, of the central line of the saw-cut in the lead, according to the polarity imparted to the electro-magnet.

13. The β rays have much greater penetrative power than the α rays; they are easily deviable by being placed in a magnetic field, and they show that they are negatively charged by their behaviour therein, and also by their power of communicating negative charges to other bodies. To Becquerel are due these experimental demonstrations of the deviability of the α and β rays, he being the first to devise the plan of placing the radium in a slit in a block of lead superimposed on a sensitive plate, and lying at the same time between the poles of a powerful magnet. Professor and Madame Curie showed that the β rays, which could traverse aluminium sheet, etc., if allowed to fall on a body surrounded by air, do not impart any charge to it; since the air itself is rendered conducting, so the charge leaks away as soon as it is imparted. If, however, the body subjected to the influence of these β rays be enclosed in a vessel in which a

very high vacuum is maintained, the body acquires a negative charge, and from it can be obtained (as long as it is subjected to the action of the said rays) a continuous stream of negative electricity.

14. The γ rays are gifted with extraordinary penetrative power. Except in very radio-active bodies, such as radium, they are difficult of detection. They appear to be a very penetrating variety of Röntgen ray, if they are not actually the X rays themselves. They appear to carry no electric charge with them, for they are not deviable under the influence of the most powerful electro-magnets. The emission of α rays seems to be unaffected between temperatures ranging from red heat on the one hand, and the cold of liquid air on the other. It depends solely on the amount of radio-active matter present, and is not influenced by its admixture with other bodies.

15. It is possible that the above-mentioned distinction between the "emanations" and the "rays" thrown off by radium, will not be long maintained; for recent observations by the Curies, by Sir William Crookes, by Mr. Soddy, by Sir William Ramsay, and last, though not least,

by Professor Rutherford, are pointing in the direction of showing that all the effects described are due to one cause only—namely, the disintegration of the so-called "atom." As, however, this would lead us into the domain of speculation and of theory, while this chapter is devoted to a description of the *facts* only connected with radium, we advert here only to the possible change of nomenclature of "emanations" and "rays"; more especially as we shall dedicate a separate chapter to the consideration of the theoretical views held by the different scientists who have made this interesting subject their study.

16. We have pointed out (*see* section 9) that the *emanations* from radium can and do affect sulphide of zinc most powerfully, causing it to glow with brilliant phosphorescence. Professor Curie has shown that this emanation has the property of being transferable from one vessel to another like a gas, and can be confined or allowed to flow therefrom by the turning of a stop-cock. To prove that the emanation was actually *material*, and not simply a form of energy, the Professor devised the following experiment. A tube, having a small bulb

at one extremity, is bent at right angles, and to the other extremity is welded another tube, parallel to the first portion. This latter tube has blown on its lower end two other bulbs, of which the lowest is smaller than the other (*see* Fig. 4, in which T, T, T, are the joined tubes, S and S′, well-fitting glass stopcocks; R, the bulb in which a small quantity of radium, or its solution, is placed;

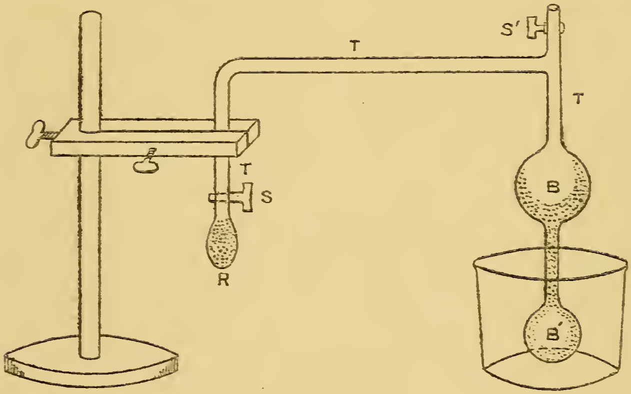

FIG. 4.

B and B′, being larger bulbs, in both of which a small quantity of the yellow zinc sulphide is placed). To perform the experiment, the stopcock S is closed, while S′ is opened, and, by means of a connection between the projecting portion of the tube T and an air-pump, the air is exhausted from the bulbs B and B′. When this has been done, the stopcock s′ is closed. On darkening the room, it is readily seen that the zinc sulphide is unaffected, since there is no appearance of any glowing or phosphorescence, as would be the case if any "rays" (known to be able to traverse the glass) were capable of setting up this phenomenon. But if the stopcock s be now opened, the zinc sulphide contained in *both* bulbs begins to shine brilliantly—so brilliantly as to be visible in a darkened place at a distance of a hundred yards or more. The inference deduced from this is, that since the zinc sulphide is unaffected by the rays β and γ, which are known to traverse glass and air freely, it must have been influenced by *something else*. That this "something" is a material body, and not "a ray," is well proved by continuing the experiment on the lines suggested by Professor Curie. If the stopcock s be closed so as to cut off all communication between the radium and the two bulbs, B and B′, and this latter bulb be plunged into a vessel containing *liquid air*, so as to bring down the temperature of this latter to a very low degree, we shall find that the light in the upper bulb, B, will gradually diminish, while that in the lower will become proportionately more brilliant, until finally the glow will be visible in the lower bulb, B′, only; proving that the emanation must consist of some material gaseous matter, capable, like other gases, of condensation. Basing himself on the results of these experiments, Sir William Crookes devised his "spinthariscope," which consists virtually of a little screen covered with the yellow zinc sulphide, in front of which, at a distance of $\frac{1}{25}$ of an inch, is stretched a wire, bearing a minute quantity of radium salt on the surface opposite the screen. On examining this in a darkened place with a lens magnifying about twenty diameters, or, better still, under a microscope furnished with a $\frac{1}{2}''$ objective, it will be seen that the screen is continually emitting little sparks, which, if the radium salt is approached closely to the screen, increase in brilliancy and frequency. At Fig. 5 we give a sectional view of a simple form of spinthariscope. As it is essential, in order to obtain the best visual results, that the screen should be accurately in focus, the lens must be capable of adjustment, to suit varying sights. For this reason the lens is mounted at the bottom of a tube, sliding in the main tube, at the farther extremity of which is the radium-coated wire and the zinc-blende screen. We shall revert to a consideration of the spinthariscope when we study Sir William Crookes' views of the cause of the phenomena. That these "emanations," though undoubtedly of material nature, must be matter in a highly attenuated form is proved by another recent experiment of M. Curie's, in which a box made of platinum was pierced with two minute holes, so minute that the box would retain a vacuum; yet the emanations from radium were able to pass freely. We have already noticed that the emanations and rays thrown off by radium confer on most bodies the power of phosphorescing, and in point of fact of behaving to a great extent like radium itself. But the bodies thus rendered radio-active, lose this property after some time; dependent partly

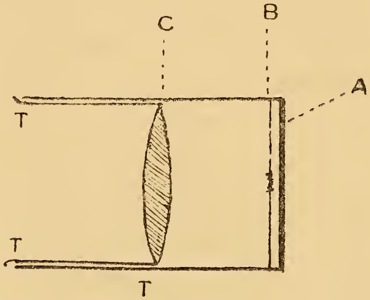

FIG. 5.

SECTION OF CROOKES' SPINTHARISCOPE.

T—The outer containing tube.
T, T—The sliding tube, for focussing.
A—The screen, coated inside with blende.
B—The wire supporting the speck of radium salt.
C—The magnifying lens.

on the nature of the substance, and partly on the fact of their being confined, or open to the action of the air. For instance, a piece of lead rendered radio-active by exposure to the influence of radium, and enclosed in a sealed glass tube, was found to lose half of it acquired radio-activity in four days, and so on in like proportion. A similar piece of lead, left freely exposed to the air, loses its radio-activity at the rate of one-half in every five-and-twenty minutes. This acquired radio-activity manifests itself, not only visually in the form of phosphorescence, but also with regard to the power of impressing the photographic plate, even through a screen of opaque matter, such as a board or a sheet of black paper, be placed between the "induced" radio-active body and the sensitive plate. The peculiar properties of radium are not diminished by exposure to the intensest possible degree of cold—*viz.*, that of liquid hydrogen, which, far from exerting any reducing influence, appears rather to heighten the radio-activity of the body. Exposed to a bright red heat, the radium appears to part with its emanations pretty suddenly, and at the same time to lose its luminous radio-activity; but it reacquires its pristine properties if allowed to rest for two or three days, and this without any appreciable loss or gain of weight. The radio-active effects, especially that of setting up luminosity, are not visible to the same extent on all bodies subjected to its influence; it is much more marked in the case of the diamond than in that of glass, or "paste," usually employed to simulate this gem. This may be of service in distinguishing a real stone from an imitation. One of the most astonishing properties of the radium rays (or emanations ?) is their effect upon animal life. We have already seen (section 10) that the proximity of radium to the human skin is sufficient to set up dangerous sloughing sores. The bad results do not become evident immediately on exposure to the rays, but occur after some time, which may be delayed for weeks, even if the emanations were not very powerful or long continued. Besides the sloughing sores, death from paralysis and congestion of the spinal cord may follow. Blindness is also a frequent consequence. But from a series of experiments performed by M. Danysz at the Pasteur Institute, it would appear that, in certain cases, benefit may accrue from exposure to the radium rays in a weak form, and in certain other instances animal life has been prolonged far beyond its natural limit by exposure to the influence of radium. This result is at once so astounding and so interesting that we give the details in full: On February 3rd, 1903, M. Danysz placed in each of two separate and similar glass flasks, three or four dozen of the larvæ of *Ephestia kuehniella*, a little moth, the caterpillars, or *larvæ*, of which feed on flour. Sufficient flour was placed in both flasks to fully nourish the little grubs, and to allow them to reach the perfect state. One of them, called the "control flask," was left in the ordinary condition; the other was exposed for a few hours to the influence of the rays emanating from radium. After several weeks, it was found that, whereas the larvæ in the "control" flask had gone through their usual metamorphoses, having changed into moths, which, in their turn, had laid and hatched eggs, that had likewise produced moths, those in the "radium" flask had nearly all perished. Some few, however, of these, that had hidden themselves in the flour, and therefore had shielded themselves from the greatest intensity of its action, were still alive. But not as *moths*: they were still in the state of *larvæ*. In the ordinary course they should have turned into moths and have perished in about one third of the time. In other words, they had lived already, as *grubs*, about three times as long as the time allotted to them by Nature. From this it would appear that mild radium rays retard development. To give the reader an idea of what this extraordinary effect is, we might exemplify it by saying that, if the results were the same when human beings were subjected to the same treatment, then we might reasonably expect that, if a young lady of eighteen were exposed for a few hours to radium rays of suitable mildness, she would, at eighty, present the same charming, youthful appearance as she wore at the time of exposure! This retardation in natural development seems to render itself evident in different ways, according to the creatures subjected to the rays, or emanations. M. Bohn, of the Sorbonne Biological Laboratories, has shown that tadpoles subjected to their influence grow in the usual manner until they reach the transition stage, in which they should acquire gills instead of tentacles for breathing. At this point (which is generally reached on the eighth day) the "radium" tadpoles became true "monsters," developing a novel kind of breathing apparatus at the back of their heads, which become wrinkled in an extraordinary fashion. Similar results have been obtained by M. Bohn, as a consequence of exposing the eggs of toads and of sea-urchins to the influence of radium. With regard to these latter, he found it possible to hatch out *unfecundated eggs*, provided they were previously exposed to the radium influence.

17. It is only natural that such marked effects on cell growth, as manifested by the above experiments, should have raised hopes in the mind of the medical profession that exposure to the influence of the radium emanations, in a mild form, might prove beneficial in modifying abnormal cell growths such as cancer, lupus, and certain skin diseases. Dr. Danlos, of the St. Louis Hospital of Paris, has treated patients for lupus in this manner, with the result, first, of setting up a period of irritation, succeeded by a healing process which culminated in healthy white cicatrices. Many patients subjected to this treatment have had no relapse for

months; but it would be premature to state that a lasting cure has been effected. With reference to cancer, the evidence is not, up to the present time, so complete; but a London physician of repute has lately reported that he has cured a case of cancer by the aid of radium. It must, however, be borne in mind, in this connection, that there are many forms of tumours, commonly called cancer, such as *epithelioma*, *columnar-celled*, *scirrhus*, *encephaloid*, *colloid*, etc., and it may well be that while the radium treatment would possibly benefit a patient suffering from some one of these, it might prove injurious in others. The mode of treatment adopted in the Paris Hospital above referred to, consists essentially in enclosing a minute portion of the radium salt (or of some body rendered temporarily radio-active by previous exposure to the radium emanations) between two thin metal discs, about two inches in diameter, of which one is of copper, and the other of aluminium. This latter is very thin, and therefore allows the β rays to pass, while it blocks almost entirely the "emanations," or α rays (*see* section 12). This "sandwich" is placed, aluminium face downwards, upon that portion of the body to be subjected to the treatment, and allowed to remain there for about fifteen minutes a day, for periods extending over weeks, or even months. Nothing else is required, except, of course, the usual cleansing, dressing, and bandaging.

18. Among the really "chemical" properties of radium, we may note its effect upon phosphorus ; exposed to its emanations, ordinary phosphorus changes into the *red,* or amorphous form.* Like phosphorus, radium appears to promote the production of ozone in the air. It has also a very peculiar influence upon quartz and glass ; a solution of a radium salt imparting to glass a brownish or violaceous colour. Whether this colouration be due to some combination of the radium with the lead, iron, or manganese present in most samples of glass, whether it depends on the formation of a silicate, or simply on a molecular alteration in the surface of the glass, has not yet been decided. It is, however, remarkable that the acquired tint is permanent, unless the glass be raised to a red heat. Another notable property which, however, may be due to a great affinity for

* May this effect not be due in part to some bromine liberated from the radium bromide?

oxygen (similar to that of potassium, sodium, etc.) is that the solution of a small quantity of a radium salt in water is constantly followed by an extrication of hydrogen gas. Owing to the extremely minute quantities of radium salts at our disposition, these results have not yet been fully studied, so that it is not certain, especially in the latter case, whether the radium itself has undergone any perceptible change in diminution in weight or bulk. Like the other bodies belonging to this group, radium salts communicate a marked colour to the flame of alcohol ; in this case, a rich crimson is the result. Of the salts of radium, we are acquainted with the sulphate, which is somewhat similar to the barium salts, but much more soluble in water, with the nitrate, the chloride, and the bromide. In many of their properties (excepting, of course, their radio-activity) they present much resemblance to the corresponding salts of barium and strontium. They are, however, more soluble than the former. Of the "earthy" metals, the only one which shares in any degree the radio-active properties of radium, is *thorium*. We shall make further mention of this body, when we enter upon the consideration of the various theories propounded by the different scientists who have attempted an explanation of the causes of the apparently inexhaustible production of light and heat by radium.

19. The spectrum of radium has been studied, both when produced by the aid of the electric spark, and when produced at ordinary temperatures by its own phosphorescence. In the former case, its general characteristics are similar to the spectra of calcium, strontium and barium; that is to say, beginning at the red, or least refrangible end of the spectrum, we have a number of lines, starting from B, and extending nearly to F, as shown at Fig. 6. Sir William Huggins has also noted a line in the violet, which, however, seems to have escaped the attention of other observers. But the "phosphorescence" spectrum of radium is totally different to this. After many trials, and using a spectroscope, the collimator of which had a wide slit, to admit as much light as consistent with getting lines of not too great breadth to be measurable, the same gentleman was able to get a photograph of the spectrum. This required seventy-two hours' exposure. The result was a picture showing eight bright lines in the ultra-violet. These were accom-

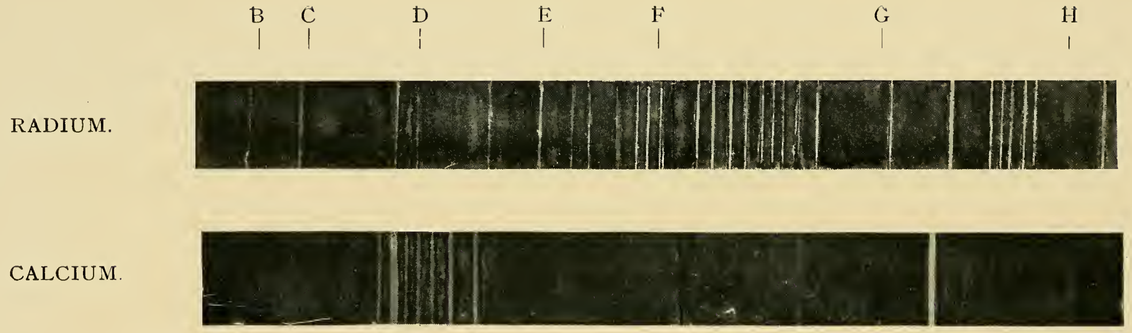

FIG 6.—COMPARATIVE SPECTRA OF RADIUM AND CALCIUM.

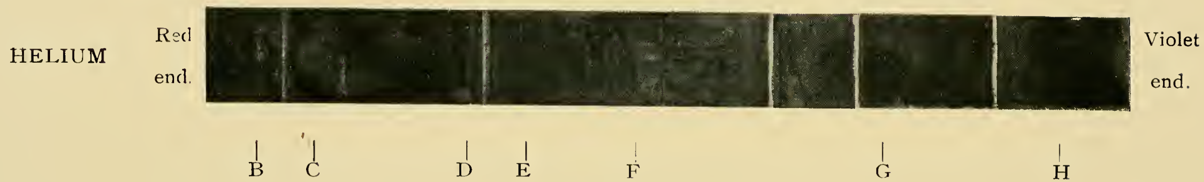

FIG. 7.—THE FIVE CHARACTERISTIC BRIGHT LINES OF THE SPECTRUM OF HELIUM.

panied by a few faint lines, and an indication of a faint continuous spectrum. But the most notable point about this "phosphorescent" spectrum is that, with the exception of the one line in the violet noted above, the lines are quite dissimilar to those of the ordinary "spark" spectrum of radium; while, on the other hand, five of the eight lines bore some resemblance to those of the gaseous element *helium* (see Fig. 7), which occurs in the photosphere of the sun, and has been detected in the mineral *cleveïte*. Another spectrograph, the result of 216 hours' exposure, showed a marvellous likeness to the band spectrum of *nitrogen*. From this, it would appear that the "emanations" (or α rays?) which, as we have already seen, can be condensed on the surface of bodies, consist essentially of helium, or, at all events, finally break up into helium. Recent experiments of Mr. Soddy and Sir William Ramsay tend strongly to confirm this view. We shall revert to this subject in a later chapter.

20. Recently, it has been shown by Professor Schuster that it is at least probable that the heating effects of radium are also due to these emanations. A thermopile was so arranged that one junction could be maintained

at a low negative potential. A stream of air, carrying with it some of the emanations from radium, was caused to play upon this junction. By this means, the emanation (which, as we have already noticed at section 12, carries with it a positive charge) was condensed on this junction. Each of the two junctions of the thermopile were then placed in separate vessels, both being at the same temperature. The free extremities of the thermopile were then connected up to a delicate galvanometer. It is evident that if both junctions of the thermopile remained at exactly the same temperature, no current would be set up, and no deflection would be shown by the galvanometer. As a matter of fact, however, the galvanometer soon gave evidence of the passage of a current, in such a direction as to prove that the temperature of that junction which had received the impact of the radium emanations, and which was coated with them, was rising. This rise in temperature lasted about as long as any ordinary substance, exposed to similar emanations, retains its power of emitting light. This experiment, in connection with that of Professor Curie described in our section 16, seems to point strongly to the assumption that the heat and light (and, probably, also the electrical effects of radium), are due, not to the radium *per se, but to some emanations thrown off by it,* which emanations can be blown away, or driven off by exposure to a red heat, but which the radium has the power, either of reabsorbing from surrounding bodies, or of reconstituting from its own mass!

21. Mr. Skinner has laid before the Physical Society the results of an investigation made by him into the photographic effects of radium, from which it would appear the β and γ rays, although able to traverse bodies opaque to ordinary light, possess, in their action on the sensitive film, properties closely allied to those of light, inasmuch as a prolonged exposure to these rays, far from producing a more intense image, actually has a reducing effect, so that a fainter image is the result. Moreover, a plate exposed to the light of an electric spark, was shown to have the image completely reversed by a subsequent exposure to radium bromide rays. In taking a radiograph, say, of a thin coin placed in a dark slide over a sensitive plate, with a tube of pure radium bromide placed over all, at a distance of one inch from the

surface of the sensitive plate, an exposure of from three to four hours will be found ample to produce a good image.

22. One property of the radium salt, which is worthy of notice, is that observed by M. Curie. Desirous of testing the effect of high temperatures on radium, he enclosed about one decigramme (about 1½ grains) in a small tube, which in its turn was enclosed in a larger outer tube. A vacuum was maintained in the tubes, which were then placed in an electric furnace, and the temperature raised to about 2,000° Fahr. At about this point a violent explosion took place, which shattered the tubes and dissipated their contents. M. Curie has ventured no explanation of the cause of this sudden explosion ; whether it depended on a rapid expansion of the rarefied radium itself, or whether it was due to the presence of some impurity which, with the chlorine &c. (of the radium chloride or bromide), gave rise to the production of a compound similar to the explosive chloride or bromide of nitrogen, is entirely a matter of conjecture. It would appear that radium, although present in very minute quantities in the different minerals and ores found on the earth's crust, is pretty widely distributed.

In our own country, traces have been found in the waters of the springs at Bath. In America, Professor Magie has discovered and extracted radium from *carnolite*, a mineral which is found abundantly at Utah, and he predicts that American radium will soon be abundant and cheap. At Llano (Texas) it appears that vast quantities of earth containing radioactive matter have been found. Besides the present source of radium, that is to say at Joachimsthal, on the Bohemian side of the Erzgebirge, there is that of the by-product of the silver ores which are extracted on the Saxony side. Radium also occurs at other points in Saxony, as at Vereinigtfeld, in the Forsten Mountains, near Johanngeorgenstadt. At Cornwall, the precise locality being Coombe Farm, near St. Stephen, Branwell, samples of ore have been found, which appear to be rather rich in radium. It will be borne in mind that uranium was found in Cornish mines some years ago. In view of the fact that radium belongs to the so-called "alkaline earths" group of metals, it is highly probable that an examination of our minerals, witherite, heavy spar, strontianite and celestine, would lead to the detection of radium in these substances.

We close this chapter with a short summary of the more striking properties of radium, as given by M. Curie himself, in 1903, in a lecture at the Royal Institution, shortly after the discovery and extraction of radium bromide in a fairly pure form. He stated :— Radium is a substance, so called because it emits "rays," which, when thrown on a sensitive screen coated with certain other substances—*e.g.*, zinc sulphide—render the screen luminous. The nature of these "rays," which have been investigated by Sir William Crookes, is in itself sufficiently puzzling. A magnifying glass shows the sensitive screen to become luminous under the impact of *tiny particles*. These particles seem to be infinitely numerous—a minute quantity of a radium salt will temporarily enable every vessel and object near it to render the screen luminous ; and yet no diminution can be observed in the mass of the radiating body. M. Curie has passed from these light-producing properties of radium to discover in it the much more unique property of emitting heat. His experiments, described in *The Times* of March 25th, 1903, showed that it continuously emitted heat for months, without any combustion or any change in its molecular structure. He ascertained that radium maintains its own temperature at about 2.7° Fahrenheit above that of its surroundings: that half-a-pound of it would evolve per hour as much heat as would be given off during the combustion of one-third of a cubic foot of hydrogen gas; and after doing this for indefinite periods, it would be found not only molecularly unaltered, but without any apparent loss or exhaustion of this peculiar heat-producing power.* An effect so considerable upon the world of matter and molecules was produced without any discoverable cause within that world—as if by a continuous act of spontaneous creation of heat and light the explanation given for the phenomenon of light-production—*viz.*, that the minuteness of the emitted particles prevents the observation of their removal from the mass of radium—is incapable of accounting for the immensely greater liberation of energy implied in the heat emission. This latter statement is open to doubt; because we know that *light* requires for its manifestation a much greater expenditure of energy than

* This statement is based only on calculation, since the total amount of purified radium salts at present (1904) existing in all the world, does not exceed four grammes, or, say, one-eighth of an ounce.

heat, and, as a matter of fact, we are able to transmute light into heat by simply lowering the vibration rate. Radium, apparently, may absorb some form of ambient energy quite unknown to us, to whose action the ordinary substances of the molecular world are indifferent or irresponsible. This energy may be all about us! We cannot gauge its possibilities or resources: we knew nothing of it till yesterday, and only know it now as rendered evident by radium. "The conception of different forms of energy, ambient and ubiquitous," remarks the *Manchester Guardian*, "separated, as it were, by watertight compartments which only the freakish action of one rare substance is known to break down, is very different from that which dawned on the world when ordinary heat, light, and motion were first realised as being easily transmutable forms of one phenomenon. If there were only more radium in the world, we could keep the world warm with it, when the sun went out."

Polonium, which, along with actinium, is found associated with radium in the Bohemian pitch blende, was discovered at the same time as radium by the Curies. It has recently been receiving attention from Professor Markwald at Berlin. From experiments instituted by him, it would appear to be even more radio-active than radium, shining more brilliantly in the dark, and setting up a brilliant greenish phosphorescence in barium platino-cyanide, or in zinc blende placed in its neighbourhood. The electro-dissipating power of its emanations is also more powerful. It is only fair to remark that the professor was experimenting on pure polonium, $\frac{15}{100}$ of a grain of which were obtained from two tons of ore, at a cost of £13.

CHAPTER IV.

THEORETICAL CONSIDERATIONS.

23. In order that the reader may be able to appreciate the extent to which the study of the properties of radium and the allied bodies, uranium, thorium, polonium, actinium, etc., have affected the views of scientists as to the ultimate constitution of matter, it will be necessary to lay before him a very brief outline of the theories which were accepted before these radio-active bodies were discovered. As far back as the times of Democritus and Leucippus, the ancients held the view that all matter was constituted of an aggregation of minute *grains* or *atoms*. These atoms were, in their opinion, *indivisible:* that is to say, they were the minutest particles to which it was possible by any means to reduce matter. The idea that these atoms were in motion came later on; as knowledge of physical facts extended, so it was found that analogy and probabilities indicated that the atoms were endowed with

continuous motion, *not* of translation, but rotary on an imaginary axis, like a top, or undulatory with respect to one another, like the waves of the sea. Descartes, in or about 1644, expounded his theory of *vortices*. But the vortex theory requires the assumption of *matter* to be thrown into this whirling motion, or else that energy itself (ether ?) should have this vortex motion, each complete whirling ring thus constituting the atom. In this aspect, *matter* has no material existence ; but is simply a manifestation of energy in vorticular motion. All the different "elements," or indecomposable bodies with which we are acquainted, would have but one basis : the physical properties by which we differentiate them would be due simply to higher or lower speeds of rotation, or to the different modes in which the vortices become interlinked. John Dalton, in 1802, enunciated the "atomic theory," which, until quite recently, has been accepted by scientific men as agreeing most perfectly with known facts, and which has enabled them to place practical chemistry on the firm basis on which it stands at present. An atom, therefore, according to this view, is the smallest particle to which it is possible to reduce matter. "Elements" are bodies in which the constituent atoms are all of the same nature; and which, therefore, are indecomposable; in other words, from any given element it is impossible (except by adding other bodies to it) to extract any other element from it. Taking, for example, the well-known elements gold, lead, and sulphur, it has been found impossible by any known mode of treatment (except, as we have said before, by the addition of other substances to them) to extract from them any other body but gold from gold, lead from lead, or sulphur from sulphur. Each atom of any one given element has the same size, weight, etc., and is charged with the same given amount of energy or force. By virtue of this energy, it is capable of entering into combination with one, two, or more atoms of some other element or elements, endowed with more or less energy, in certain definite proportions. The atom, like the energy which accompanies it, is considered to be not only indivisible, but indestructible. Each element is found to have a certain definite *atomic* weight, so that when converted into the gaseous form, equal volumes of the various elements have different weights, related to the proportions in which they can and do combine the one with the other. Now, the peculiarity of radium (and perhaps others of the radio-active elements) is, that according to the views of many of the scientific men who have experimented with this interesting body, the radium atom undergoes a kind of spontaneous disintegration, with the result that light and heat (forms of energy) are liberated, along with at least one element—helium—of lower atomic weight. Of course, this notion is quite contrary to our preconceived theory of the constitution of matter. Either our view of the atom being indivisible is erroneous, an assumption which would compel us to return to something like the Descartes' theory of the vortex-energy constitution of matter, or else the body which we consider as an element, under the name of radium, is actually a compound, or, finally, that the radium atom is capable of absorbing from surrounding bodies some unknown form of energy, which it can render evident as heat and light. But the fact is, that the amount of radium, even in the form of bromide, chloride or nitrate, at our disposition, has been, up to the present time, so minute, that it is premature to build up any theory which, when we can experiment upon *pure* radium in an uncombined state on a larger scale, may have to be greatly modified if not altogether discarded. The very fact that not only helium, but oxygen, hydrogen, carbon dioxide and nitrogen are found occluded in radium bromide, shows how essential it is to the solution of the problem that a fair quantity of pure radium should be experimented upon before any satisfactory theory can be formulated.

24. To enable the reader to judge for himself of the tenability of the theories advanced to explain the behaviour of the radium salts, we lay before him the views of several scientific men, beginning by Prof. J. J. Thomson :—" It has been suggested that radium derives its energy from the air surrounding it, that the atoms of radium possess the faculty of abstracting the kinetic energy from the more rapidly moving air molecules, while they are able to retain their own energy when in collision with the slowly-moving molecules of air. I cannot see, however, that even the possession of this property would explain the behaviour of radium. For, imagine a portion of radium placed in a cavity in a block of ice. The ice round the

radium gets melted. Where does the energy for this come from? By the hypothesis, there is no change in the energy of the air-radium system in the cavity, for the energy gained by the radium is lost by the air, while heat cannot flow from the outside into the cavity, for the melted ice around the cavity is hotter than the air surrounding it. I think that the absence of change in the radium has been assumed without sufficient justification; all that the experiments justify us in concluding is, that the rate of change is not sufficiently rapid to be appreciable in a few months. There is, on the other hand, very strong evidence that the substances actually engaged in emitting these radiations can only keep up the process for a short time: then they die out, and the subsequent radiation is due to a different set of radiators. *There* seems as clear a proof as we could wish for that the radio-activity of a given set of molecules is not permanent. This want of permanence is shown by the radio-active emanations from thorium and radium, and by the induced radio-activity exhibited by bodies which have been negatively electrified and exposed to these emanations or to the open air: in all these cases, the radio-activity ceases after a few days. I have recently found that the water from deep wells in Cambridge contains a radio-active gas, and this gas, after being liberated from the water, gradually loses its radio-activity; the radio-activity of polonium, too, is known not to be permanent. The view that seems to me to be suggested by these results is, that the atom of radium is not stable under all conditions, and that among the large number of atoms contained in any specimen of radium, there are a few that are in the condition in which stability ceases, and which pass into some other configuration, giving out as they do so a large quantity of energy. I may, perhaps, make my meaning clearer by considering a hypothetical case. Suppose that the atoms of a gas, X, become unstable when they possess an amount of kinetic energy one hundred times, say, the average kinetic energy of the atoms at the temperature of the room, there would, according to the Maxwell-Boltzmann law of distribution, always be a few atoms of the gas possessing this amount of kinetic energy; these would, by hypothesis, break up; if, in so doing, they would give out a large amount of energy in the form of Becquerel rays, the gas would be radio-active, and would continue to be so until all its atoms had passed through the phase in which they possessed enough energy to make them unstable: if this energy were one hundred times the average energy, it would probably take hundreds of thousands of years before the radio-activity of the gas was sensibily diminished. Now, in the case of radium, just as in the gas, the atoms are not all in identical physical circumstances, and if there is any law of distribution like the Maxwell-Boltzmann law, there will, on the above hypothesis, be a very slow transformation of the atoms accompanied by a liberation of energy. In this hypothetical case, we have taken, of a certain amount of kinetic energy as the criterion for instability, the argument will apply if any other standard be taken." From this it will be seen that Prof. J. J. Thomson leans towards the belief that the phenomena of light and heat production by radium are due to the slow but continuous resolution of its complex atom (?) of high atomic weight, into some simpler form, a portion of its inherent energy being, during this process, set free.

We may now pass on to consider the views held by Sir Oliver Lodge, who, in the *Nine-*

teenth Century for July, 1903, summarises the various facts that have been discovered about radium and other radio-active substances :—
" The primary and important phenomenon," he considers, "is the throwing off from a radio-active substance of atoms of matter at an almost inconceivable speed—atoms which are, however, quickly stopped by any obstacle." Going on to describe Professor Rutherford's experiments on this substance, Sir Oliver Lodge points out that the atoms thrown off from a radio-active substance are not atoms of the substance itself, but belong to a different body, possessing a much lower atomic weight. The emanations leave behind them in the radium a sort of heavy gas, again a different element, which is itself unstable, and which sends out radiations of its own. Thus the radium is being split up into a " chain of substances " in descending scale of atomic weights, different elements, which leave a relation to their parent. The inconceivable smallness of the products of this disintegration prevents their being followed and analysed. But it also suggests that the same kind of " breaking up " may be going on in other elements, on a scale too small for observation. Many of the chemical ele-

ments form groups, related in their qualities, and showing a sort of progression in their atomic weights, which might suggest that they are the results of such disintegration, and which, under various cosmic conditions, have settled down into their present apparent stability. The recognised elements which we know so well, must clearly be comparatively stable and persistent forms; but it does not follow that they are infinitely stable and perpetual; the probability is that, every now and then, whether by the shock of collision or otherwise, the rapidity of motion necessary for instability will be attained by some one atom, and then that particular atom will fling off fragments and emit the rays of which we have spoken, and begin a series of evolutionary changes, of which the details may have to be worked out separately for each chemical element. In Sir Oliver's view, the atom is not simple, but complex; it is composed of an aggregate of smaller bodies in a state of rapid interlocked motion, restrained and coerced into orbits by electrical forces. An atom is fairly stable, but not eternal. Every now and then, one atom in a million, or rather, in a million millions, gets into an unstable state, and is then liable to break up. A very minute fraction of the whole number of atoms of a substance does actually thus break up, probably by reason of an excessive velocity in some of the moving parts; an approach to the speed of light in some of their internal motions—perhaps the maximum speed that matter can ever attain—being presumably the cause of the instability. In this cosmic process, the gradual break-up into simpler forms of a complex arrangement built up untold ages ago, we may possibly find the explanation of the light of the glow-worm and the firefly; that may be using the energy of the world's break-up to produce their light. The light of the glow-worm, he says, is accompanied by a trace of something which can penetrate black paper, and affect a light-screened photographic plate. He asks, "Has the insect learnt how to control the breaking down of the atoms, so as to enable their internal energy, in the act of transmutation, to take the form of useful light, instead of the useless form of an insignificant amount of heat or other kind of radiation effect?" In a lecture delivered by Sir Oliver at the Town Hall, Birmingham, January 5th, 1904, he said:—"In science the calculator and interpreter and wielder of theory is most looked up to by his colleagues, but the experimentalist is usually best understood. The man who can combine theory and practice to the full is a leader in science. A bare fact by itself is nothing, or is little, it is a bald, bleak thing, until it is clad in theory. Sometimes a fact is born before its clothes are ready. Sometimes a 'layette' has been provided before the fact is born. Radium is in the latter predicament; its properties, as now known, go indeed beyond the anticipation of theory, but they are all in a line with theory, and there is no difficulty in understanding them and fitting each into its niche. Not one fact concerning radium need stand out in the cold for lack of theoretic shelter. This circumstance is not generally appreciated. It is thought that the behaviour of radium revolutionises the doctrines of science. It does revolutionise some of them, but the revolution has been prepared beforehand, far away from practical chemistry, in the study of the mathematician, in the laboratory of the pure physicist. A few of the leaders of physical science were on the look-out for evidence of some kind of atomic radiation, and, after the discovery of spontaneous radio-activity, were on the further look-out for some kind of instability, or some rearrangement of parts in the atom of matter. Some thought that X radiation might be found in conjunction with the phenomenon of phosphorescence, and it was owing to a vague and indiscriminate suggestion of this kind by the French mathematician, Poincaré, that the discovery of radio-activity was actually made by Becquerel in Paris in the year 1896, one year after the empirical, and at first puzzling, discovery of the X rays themselves had been achieved by Röntgen in Germany. For the X rays, theory was not ready, it came later. For all the properties of radium, theory was ready, and, if not exactly waiting, was available at the moment each fact was known. In this lecture I shall run over a few of the salient facts without attempting the impossible task of completeness in a single hour; and I shall endeavour to state their meaning, as now apprehended by those with whose views I am now in accord, without delaying to controvert opponents, and without pretending to marshal all the arguments and reasoning on which those views are based. It is, indeed, the meaning of the facts on which I shall mainly concentrate attention, and for brevity I shall have to be dogmatic, and to deal mainly with definitely stated results. To judge of the arguments on which they are based, requires long consideration and expert knowledge, but every educated person may be interested in the results themselves, and indeed it should be the privilege of the citizens of a University city to know the latest advances in science explained to them. At the outset, and to avoid disappointment, I wish to state that I intend to say nothing about the price of radium, the point which arouses most attention; nor shall I speak about its hoped-for medical uses, which is the second point of general interest, for the development of that side lies in the future. In order to be clear, I must begin with theory, and state our present view of the nature of the atom of matter. We hold this view to the labours of many, but to two Englishmen in especial do we, in my judgment, owe it. On the screen a page of the Cambridge Calendar is thrown, showing the position in the tripos for 1880 of the two great men, Larmor and Thomson, now professors, at Cambridge, of mathematics and physics respectively. From them and others we learn that electricity exists in small particles, which we can in a manner 'see' in the cathode or Crookes' rays, and which are called 'electrons.' These compose the atoms of matter. Atoms are small—300,000,000 can be in a row side by side in an inch, and there are a trillion of them in each granule of lycopodium dust. But electrons are very much smaller—100,000 of them can lie in the diameter of an atom, for they are 1,000 million million times smaller in bulk than atoms are; they are to atoms as a grain of dust shot is to the size of the Town Hall. On the screen is thrown the portrait of an atom of matter, as near as we can estimate it at present, consisting of positive and negative electricity, and nothing else—the negative electrons in a state of violent movement, with occasional possibility of escape. An electric charge in motion constitutes all electric currents and magnetism, and it possesses momentum; further, when accelerated, it should, by Poynting's theorem, generate radiation. Hence, on the new or mathematical theory, that the atom is actually so constituted, the absence of atomic radiation in the year 1895 was a difficulty; the escape of electrons as projectiles was probable; and soon afterwards it was realised that since the atom is composed of parts, the occasional disintegration of an atom was not unlikely. These three expected effects have now been experimentally observed in the radiation from two or three different elements, and constitute what are called the Gamma rays, the Beta rays, and the Alpha rays respectively. We must now leave the theorists and see what the experimentalists have been doing. The phenomenon of phosphorescence was first understood by Stokes, and, after the discovery of the Röntgen rays, the phosphorescent substance, uranium, was studied by M. Henri Becquerel in 1896, to see if it emitted rays which could affect a photographic plate, after penetrating black paper or other opaque material. Becquerel found that even when it had not been exposed to light, it did give off such rays slowly, and thereby he effected the discovery of 'radio-activity'; the most sensitive test for it being the discharge of an electroscope in the neighbourhood of the substance. All compounds of uranium do the same thing, and Schmidt found that thorium and its compounds likewise had the property. Madame Curie, then a senior student at the Municipal School of Physics and Technical Chemistry in Paris, took up the subject of radio-activity as a thesis for her doctorate, and made quantitative measurements of the radio-activity of a great number of minerals. She found that pitch blende, an oxide of uranium, especially the variety found in Bohemia, was even more radio-active than uranium itself, showing that it must contain a specially radio-active material; and this she set herself to isolate. The only test she had for it was its radio-active power, and the method was to try chemical processes upon the ore, such as solution, precipitation, evaporation, crystallisation, and the like, so as to divide the substance into two parts, and then to test which part was the more radio-active. In that way the trace of radio-active substance could be followed up through a number of chemical processes. It was found that the residue of the pitch blende, after extracting the uranium, was four and a half times as active as uranium." (Here the lecturer gave an account of the process of extracting the radium chloride or bromide, practically the same as we have given *in extenso* at paragraph 5 of this work, and then went on to say) :—" Professor Curie now joined his wife in the investigation, and by them and others many curious details concerning the behaviour of the several radio-active bodies were detected, as, for example, their activity was not constant; it gradually grew in strength, but the grown portion of the activity could be blown away, and the blown-away part retained its activity only for a time. It decayed in a few days or weeks, whereas the radium rose in strength again at the same rate that the other decayed; and so on constantly. It was as if a new form of matter was constantly being produced, and as if the radio-activity was a concomitant of the change of form. Last year, also, Professor Curie found that radium kept on producing heat *de novo* so as to keep itself always a fraction of a degree above the surrounding temperature; also, that it spontaneously produced electricity. The production of heat attracted general attention; it was taken up by the English press, and the whole thing emerged from the scientific world and came into public notice. The rays from any radio-active substance are found to be of three kinds, which can be distinguished by their powers of penetration, and by their behaviour in the field of a magnet; these are: *Gamma rays*, which are very penetrating, can be detected after passing through a foot of iron, and are possibly a variety of X rays; *Beta rays*, which consist of flying or escaped electrons; *Alpha rays*, the nature of which was investigated by Rutherford, late of New Zealand, then student at Cambridge, now of Montreal. These last were found to consist of atoms of matter, each one per cent. of the weight of a radium atom, projected from it with a velocity of a hundred thousand miles a second. These are the projectiles which make the luminous splashes on the target (or sulphide of zinc screen) in the Crookes' spinthariscope. The material which remained behind is called 'the emanations;' it is much more active and unstable than radium itself, and is the part that can be blown away like a gas. Its amount is infinitesimal, but its radio-active power enables it to be followed, and to be generally investigated. It rapidly collapses into other substances, and at the end of a few days or weeks has changed into something which is not radio-active, and can therefore be no longer followed. The whole phenomenon is intelligible and simple on the theory that activity is due to atomic disintegration; it is entirely unlike any chemical operation; it is enormously more energetic for one thing, and it is quite unaffected by temperature for another, being of the same intensity at a red heat, and at the temperature of liquid air. Rutherford's measurements last February made it probable that the atomic particles thrown away in the Alpha rays, to the bombardment of which heat-production is due, consisted of *helium*, because their atomic weight appeared to be twice that of hydrogen (like that of helium); and now quite recently Ramsay and Soddy, working together at University College, London, have confirmed this beyond cavil, by actually seeing the spectrum of helium gradually develop in an excited vacuum tube, into which only radium emanations had been put. In consequence of their observations, we see that the spontaneous breaking up of an atom constitutes a novel source of energy, larger than any previously known. The amount of energy in any weighable collection of atoms is enormous, if it could be got at; but in practice only a very few atoms are unstable from instant to instant. Most behave as if they were permanent; but they are probably none of them really and eternally permanent. The discovery of this new or intra-atomic energy affects our estimate of the possible life of the sun, and to some extent of the probable geological age of the earth. But the most important consequence is the discovery of the mutability of matter, the transmutation of elements, and the liability of material atoms to break up or explode." The remainder of the lecture was taken up with metaphysical considerations as to the bearing of these new ideas on the development of man and of nations, and wound up with these words:—"The atoms are crumbling and decaying. Must they not also be forming and coming to the birth? This last we do not know as yet. It is the next thing to be looked for. Decay only, without birth and culmination, cannot be the last word. The discovery may not come in our time, but science is rapidly growing, and it may. Science is still in its infancy. We are beginning to comprehend a few of the secrets of Nature; we are yearly coming nearer to some sort of a comprehension of the mind and method infused into the material cosmos. We now know things that have been hidden from the wise and prudent of all time. Surely somewhere there must be joy at seeing man thus entering into his heritage, and realising these primal truths concerning his material environment, whereof he has been living in ignorance all these thousands of years." From the above it will be easily seen that Lodge places no faith in the materiality of the "atom," but, like Descartes, looks upon it as a vortex of electrical energy. We can now pass on to consider the views of Sir William Crookes on this subject, as embodied in a little leaflet written by him at the time he brought his "Spinthariscope" into public notice.

Sir William Crookes has devised a very simple and convenient piece of apparatus, by means of which some of the emanations from a radium salt can be rendered visible to the eye by their effect on a fluorescent screen, usually coated with Sidot's hexagonal blende (zinc sulphide) or for other emanations with barium plantino-cyanide. This device, to which he has given the name "spinthariscope," from "σπινθαρις" *a scintillation*, and "σχοπενω" to see, may be conveniently constructed by fitting a little screen, coated with the said blende, at the bottom of a small brass tube. At a distance of about one millimetre ($\frac{1}{25}''$) from this, at its centre, is suspended a speck of radium salt (nitrate, chloride, or bromide). At the opposite end of the tube is arranged a second tube, sliding into the former, carrying at its extremity a lens, admitting of accurate focussing on the screen. This should have a magnifying power of about 20 diameters. Our Fig. 5 shows this arrangement in section. Or, if desired for microscopic observation, an ordinary microscope slide, with a "ring" cell, is mounted with the blende screen at its bottom, and the tiniest speck of radium salt affixed to the *inside* of the cover glass, which is then to be cemented down as usual. On examining either of these forms through the eyepiece, after careful focussing, the phenomenon observed is remarkable. A rather dark patch appears in the centre of the field, while all around little sparks of light, not very intense, are seen flying hither and thither, but seeming to have a general tendency towards the centre. If the speck of radium nitrate (or other salt) be arranged so as to be adjustable as to distance from the zinc sulphide screen, then on approaching to the screen the scintillations become more numerous and brighter, until when close together, the flashes follow each other so quickly that the surface looks like a turbulent luminous sea. "It seems probable," says

Sir William Crookes in a descriptive leaflet, "that in these phenomena we are actually witnessing the bombardment of the screen by the positive atoms hurled off by radium with a velocity of the order of that of light; each scintillation rendering visible an impact on the screen, and becoming apparent only by the enormous extent of lateral disturbance produced by its impact. Just as individual drops of rain falling on a still pool are not seen as such, but by reason of the splash they make on impact, and the ripples and waves they produce in ever-widening circles. The emanations from radium are of three kinds. One set is the same as the cathode stream, now identified with free electrons—atoms of electricity projected into space apart from gross matter—identical with 'matter in the fourth or ultragaseous state,' 'Kelvin's satellites,' 'Thomson's corpuscles' or 'particles,' disembodied ionic charges retaining individuality and identity. Electrons are deviable in a magnetic field. They are shot from radium with a velocity of about two-thirds that of light, but are gradually obstructed by collision with air atoms. Another set of radiations are not affected by an ordinarily powerful magnetic field, and are incapable of passing through very thin material obstructions. They have about 1,000 times the energy of that indicated by the deflectable emanations. They render air a conductor, and act strongly on a photographic plate. These are the positively electrified atoms. Their mass, in comparison with that of the electrons, is enormous. A third kind of emanation is also produced by radium. Besides the highly-penetrating rays which are deflected by a magnet, there are other very penetrating rays, which are not thus affected. These always accompany the other emanations, and are Röntgen rays—ether vibrations—produced as secondary phenomena by the sudden arrest of velocity of the electrons by solid matter, producing a series of Stokesian 'pulses' or explosive ether waves, shot into space. These rays chiefly affect a barium platino-cyanide and, only in a much smaller degree, zinc sulphide. Both Röntgen rays and electrons act on a photographic plate, and produce images of metal and other substances inclosed in wood and leather, and shadows of bodies on a barium platino-cyanide screen. Electrons are much less penetrating than Röntgen rays, and will not, for instance, show easily the bones of the hand. A photograph of a closed case of instruments is taken by the radium emanations in a few days, and one of the same case by Röntgen rays, in three minutes. The resemblance between the two pictures is slight, and the differences great. The action of these emanations on phosphorescent* screens is different. The deflectable emanations affect a screen of barium platino-cyanide strongly, one of Sidot's zinc sulphide but slightly. On the other hand, the heavy, massive non-deflectable positive atoms affect the zinc sulphide screen strongly, and the barium platino-cyanide screen in a much lesser degree."

25. The views of Prof. Rutherford in this connection are highly interesting, especially as they include the behaviour of thorium and uranium. We shall, therefore, reproduce here some of his remarks which appeared in *Harper's Monthly Magazine* for January, 1904, entitled "The disintegration of the radio-active elements." After passing in review the principal facts connected with radium, as already given in these pages, he goes on to say:—"It is now necessary to consider another radio-active product of

* Should this not have been fluorescent?

thorium,* the investigation of whose properties has thrown a flood of light on the processes occurring not only in thorium, but also in uranium and radium. Early experiments had pointed to the conclusion that the radio-activity of thorium remained constant, and was an unchangeable property of that element. Yet, by a single chemical process, it was found possible to separate from thorium the greater proportion of its activity, and to concentrate it in a minute quantity of intensely active matter. If ammonia was added to a thorium solution, the precipitated thorium was found to have lost more than half its activity. When the filtrate, which was free from radium, was evaporated and heated, the whole of the lost activity was concentrated in a minute residue, which, weight for weight, was over a thousand times as active as the original thorium. This active residue was called thorium X. An examination of the variation with time of the activity of the precipitated thorium and the thorium X, revealed the remarkable fact that the thorium spontaneously regained its

* Thorium is a metal of the alkaline earth group, resembling aluminium. It is very heavy, and its atomic weight is 231.5. The oxide, thoria, is made use of in the manufacture of incandescent lamp-mantles.

separated activity exactly as fast as the thorium X lost it. The activity of the precipitated thorium, when added to that of the thorium X, was always equal to that of the thorium before the chemical process. In the course of a month the thorium X was almost inactive, while the thorium had regained its old activity. Provided sufficient time is allowed to elapse for the thorium to recover its activity, the process can be repeated indefinitely. These surprising results are completely explained by supposing that the thorium is continually manufacturing from itself a radio-active substance, thorium X, different in chemical properties from the thorium itself. The radiating power of this thorium X decays in a geometrical progression with the time, following the same law as the decay of the activity of the emanations, but at a different rate. On this view, the constant radio-activity of thorium is the result of two opposing processes—the manufacture of active matter, and the decay of activity of this matter. A further examination revealed the important fact that thorium X, and not thorium, gave rise to the emanation; for, after separation of the thorium X, the thorium does not possess at first the property of giving out the emanation, but the thorium X does. The power of thorium X of producing the emanation was found to decay at exactly the same rate as its radiating power. This law applies generally to all the active products yet obtained, showing that the radiation is an accompaniment of the change of one substance into the next. We thus see that thorium produces a succession of radio-active substances, each one different in chemical properties from the other and from the parent substance. Thorium produces thorium X, which gives rise to the emanation, and this in turn changes into the matter responsible for "excited" activity. Thorium X is soluble in ammonia; thorium is not. The emanation is an inert gas possessing no definite chemical properties.* The matter producing excited activity behaves like a solid, insoluble in ammonia, but soluble in sulphuric and hydrochloric acids. The radio-active elements uranium, thorium, and radium, exhibit distinct but yet analogous properties. Uranium produces a new product, called by Sir William Crookes uranium X, but this, unlike thorium, does not give rise

* May this not be *nitrogen?* See farther on, referring to Sir William Huggins' results with the spectrum of Radium.

to either an emanation or excited activity. There is no stage in radium corresponding to the thorium X in thorium. The radium first produces the emanation, which in turn changes into the matter producing activity. These radio-active bodies may be tabulated thus :—

Uranium.	Thorium.	Radium.
Uranium X.	Thorium X.	Radium emanation.
Final Product.	Thorium emanation.	Matter exciting activity.
	Matter exciting activity.	Final Product.
	Final Product.	

There is very distinct evidence, in addition, that the matter causing excited activity undergoes at least two further changes in the case of thorium, and three in the case of radium. Since these substances have only been detected by their power of radiating, the final product, which is not radio-active, is beyond the range of investigation by this method. The changes we have considered, although chemical in nature, are different from anything before observed in chemistry. The rate of production of active matter, and the rate of decay of its activity are not affected by any known agency. Change of temperature, which has so powerful an influence in altering the rate of chemical reaction, is here entirely without influence. The chain of substances that are being spontaneously produced from the parent element cannot be due to the breaking up of molecular systems, but must arise from an actual disintegration of the atoms of the radioactive elements into simpler forms. It is to be expected that wide changes of temperature would have little effect in altering the stability of the atoms; in fact, the general experience of chemistry, in failing to transform the elements, strongly supports such a view. The discovery that radiation from each active product consists for the most part of the expulsion with great velocity of charged atoms, about twice the mass of the hydrogen atom, allow us to make a mental picture of the processes occurring within the atom which give rise to the chain of products observed. As an example, let us consider the case of thorium. It must be supposed that a very minute fraction of the thorium atoms—not more than one per second in every million billion—for some reason become unstable, and as a result of the instability each atom throws off a fraction of its mass with great velocity. This gives rise to a radiation, consisting of α rays, which is an inherent property of the mass of thorium, and which cannot be separated by chemical means. This at once explains the presence in all the active substances of a non-separable activity consisting entirely of α rays. The expulsion of this mass leaves the thorium atom lighter than before, and must change its physical and chemical properties. The thorium atom, minus one expelled body, becomes the atom of the new substance, thorium X. The atom of thorium X is again unstable, and throws off another portion of its mass. The thorium atom, minus two expelled bodies, thus becomes the atom of the emanation. This again goes through the same process, and changes into the matter which produces excited activity, and so on. The process, once started, goes on spontaneously from stage to stage. The radio-active products given in the foregoing table thus really consist of unstable atoms, produced by the breaking up of the atoms of the radio-active elements in successive stages. The activity of each product is a result of its instability, and is a direct measure of the amount of matter undergoing change. Since the atoms of the radio-active product are unstable and continuously breaking up into new systems, the substances like thorium X and uranium X, and the emanation, cannot consist of any known kind of matter, since their life, in most cases, is not longer than a few weeks. If the radio-active elements are undergoing spontaneous transformation, their life as elements must be limited. The rate at which the process of transformation goes on can only be calculated roughly, but there is no doubt that it is extremely slow in the case of thorium and uranium. On a moderate computation, at least a million years would be required before a thousandth part of any given mass of the elements would undergo change. In radium, on account of the enormous activity of that element, the process takes place a million times faster, so that the same amount must change per year. Or, in other words, the life of radium cannot be much more than 1,000 years. The active elements must thus be considered as analagous to the radio-active products to which they give rise, with the difference that their rate of change is very much slower. The difference between these changes in the radio-active elements and ordinary chemical change in matter is clearly brought out when the amount of energy evolved during the spontaneous transformation is considered. The amount of energy emitted in the form of radiation during the life of radium is enormous compared with that liberated by any known chemical reaction. This enormous amount of energy is derived from the internal energy stored up in its atoms. Its rate of liberation, due to their gradual disintegration, is too slow to be used as a source of appreciable power, even in the case of radium. If this view of the transformation of the radio-active elements is correct, can we ever hope in the limited time to test its truth by ordinary chemical means? There is one indirect method of attack of the problem that suggests itself. Since the radio-active elements must have been radiating for geological epochs in the earth's crust, it is probable that the disintegration products would always be found associated with them. Now it is very remarkable that the gas helium, recently discovered by Sir William Ramsay, is only found in radio-active minerals. For this and other reasons it was suggested two years ago, by Mr. Soddy and myself, that helium might be a disintegration product of the radio-active elements. A few months ago this suggestion could not have been considered more than a justifiable speculation, which might possibly be put to the proof in the next decade. But the progress of science is so rapid and its methods so powerful that it seems as if this question was answered in the affirmative to-day.

"Sir William Ramsay and Mr. Soddy have recently found that helium is present in the gases liberated by solution in water of a small quantity of pure radium bromide. The quantity of helium present was very small, but was sufficient to show clearly the characteristic spectrum of this gas. When the emanation was collected in a small vacuum tube and an electric discharge passed through it, a spectroscopic examination revealed some new bright lines, which they considered were due to the emanation. In addition the spectrum of helium made its appearance, after the emanation had stood some time in the tube, and increased in brightness for several days. This remarkable result indicates that the helium is produced from the emanation, or, in other words, that helium is a true disintegration product of the radium emanation. It seems probable that the helium produced in the tube in reality consists of the α bodies which are continually projected from the emanation. The fact that the mass of the α body is about twice that of the hydrogen atom is very suggestive in this connection, since the atom of helium comes next to that of hydrogen in lightness.

"The interpretation of experimental results of such great importance on the transformation theory must naturally be accepted with reserve until it is proved beyond doubt that the helium present in radium is continuously produced from itself by that element, and cannot be derived from an external source.

"The idea that all the chemical elements are built up of some elementary unit of matter or protyle has long been familiar, and has been tentatively suggested in different forms by many prominent scientists. From evidence of a spectroscopic examination of the stars, Sir Norman Lockyer has put forward the view that the matter of the universe is undergoing a continuous process of evolution. The hottest stars consist of the lighter and simpler forms of matter, like hydrogen and helium, but at lower temperatures the more complex and heavier types of matter appear. The theory we have put forward is the exact converse of this. It demands a continuous disintegration of matter, the heavy atoms breaking up into simpler forms, and in this change the highest temperature obtainable in the laboratory has little or no influence. This process of degradation does not consist in a slow, simultaneous transformation of all the matter with a gradual alteration of chemical properties, but is a process of degradation *per saltum*, in which only a minute quantity of matter is affected at one time, and where the products are of clearly defined chemical and physical properties differing from the original substance.

"Whether this process of degradation is common to all matter or takes place only in the radio-active elements is at present a purely speculative question. There is indeed experimental evidence that ordinary matter possesses the property of radio-activity to a very slight extent. If this is not due to some slight radio-active impurity, it is strong evidence that all matter is gradually breaking up into simpler forms. The changes occurring even in radium would probably never have been observed but for its property of expelling one of the products of the change with great velocity. Matter may be slowly breaking up and yet not give rise to a radiation capable of easy detection. The process of decay may be imperceptible when judged by the life of man, but the effect is cumulative, and in the ages yet to come may reduce the matter of this earth to the simpler and more stable forms."

26. Although the "disintegration of the atom" theory has found pretty general acceptance among scientists, especially in England, it must be borne in mind that there are many scientific men of high standing whose opinions on the subject of radium are not in a line with those of Lodge and Rutherford. For instance :—

M. Berthelot, the most famous of French men of science, is not inclined to accept the theory that radium is an exception to the known laws of nature, and gives off energy without receiving any.

M. Curie's discovery, he says, is most important. The characteristics of radium have, however, not only been observed in other bodies, but appear to be common to nearly all, some possessing them to a very high degree, as in the case of radium, and in others very little.

Radium is simply a substance with an exceptional capacity for receiving the waves of energy emanating from the sun, and giving them off. Canton's phosphorus is another body performing a similar function. It emits luminous waves, which gradually lose their force, but revive immediately on exposure to the sun.

To say that radium upsets all scientific knowledge, is, M. Berthelot thinks, an utter mistake, and the practical application of its discovery is likely to be remote.

Some recent researches into the nature of the "glow" or "ordinary temperature" spectrum of radium, as compared with that given under the influence of the electric spark, made by Sir William and Lady Huggins, go a long way to prove that it is by no means certain that *helium* is the "final product" of the break-up of the radium atom. In fact, it is probable that until we can procure *pure metallic radium* in sufficient quantity to be able to verify its being really an element, free from all admixture, we shall not be in a position to decide definitely on what its peculiar properties depend. In order that the reader may be able to follow and to understand the importance of the result of Sir William and Lady Huggins' experiments, we will refresh his memory as to the work effected by the spectroscope. When a ray of light falls on the edge of a wedge of glass or other transparent material (a prism), the light is spread out into a long coloured band, called a *spectrum* (see central band on cover). This spectrum can be easily seen by nearly closing the shutters of a window facing the sun, and allowing the rays to impinge on the edge of such a prism, when a brilliant image, beginning with dark red at one end (the least refrangible rays), shading through orange, yellow, green, blue, to intense violet at the opposite end (the most refrangible rays) will be visible on the opposite wall, or on a white paper screen held at a little distance behind the prism. Now it has been found that if we can burn, or raise the temperature of any given element to such a temperature as to cause it to give off light, and place it, instead of the sun, in front of a narrow slit placed before the prism, it will give a spectrum. But this spectrum, instead of being continuous, as in the case of the sun, will show bright lines in one or more different positions of the spectrum band. Each element is found to give its own characteristic bright lines, by means of which it can be easily recognised; as the remainder of the spectrum remains dark. (It is usual to map out a spectrum into several thousand spaces, corresponding to the wave-lengths of the light required to produce the different colours.) Thus *sodium* gives a brilliant line in the yellow, *potassium* two lines in the red and one at the violet end of the spectrum, *thallium* one in the green, *indium* one in the blue region, etc. So certain and delicate are these indications that we can detect the presence of any given element by the spectroscope, even in quantities so minute as to defy every other known test. Sir William and Lady Huggins began in July, 1903, by observing the "glow" spectrum of radium with a direct vision spectroscope, using no slit, but placing a minute splinter of radium bromide, which glowed with a mere line of light, in front of the prism. This gave a spectrum which extended from the blue to about the centre of the yellow, where it became too faint to be traced any

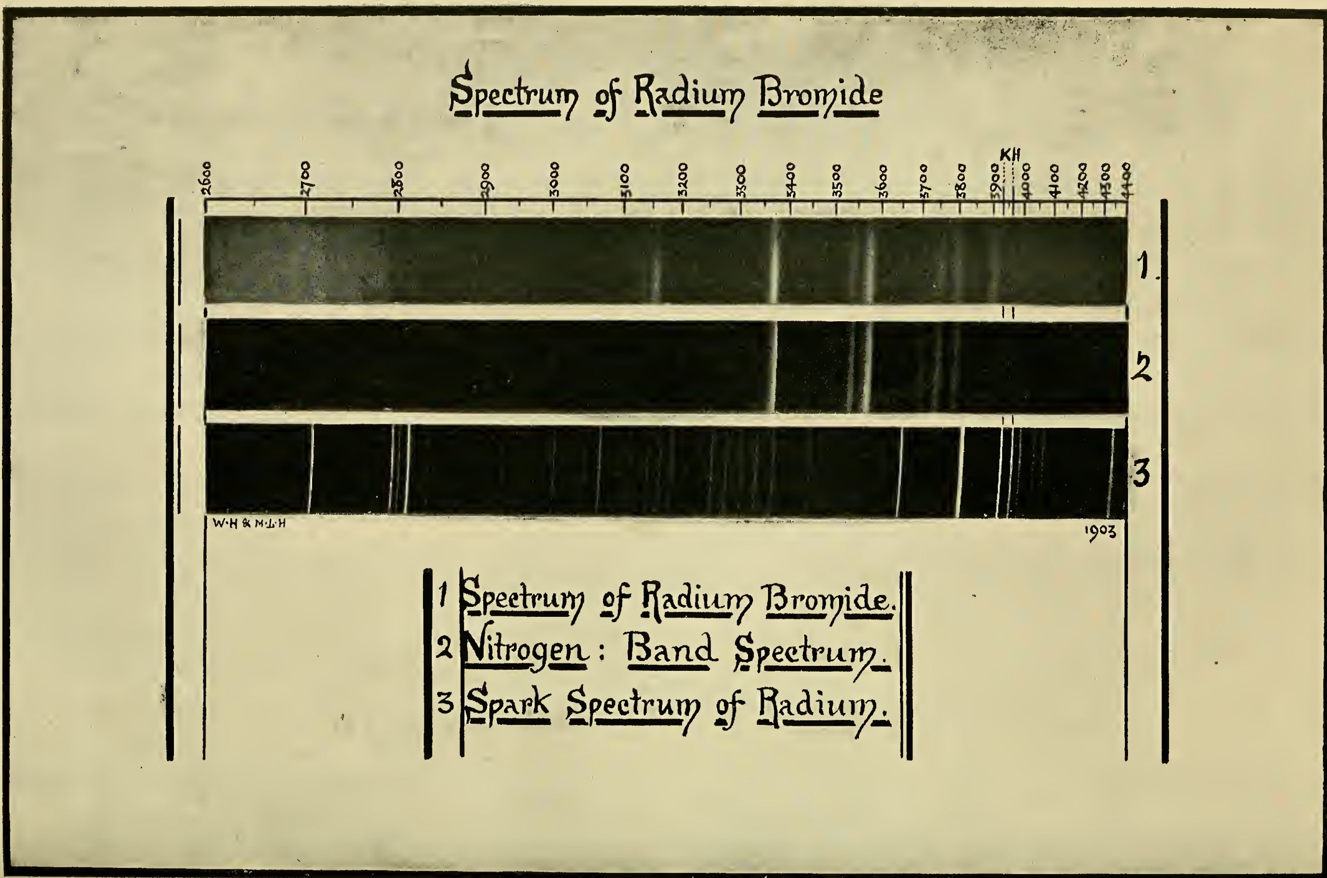
Spectrum of Radium Bromide
KH
2600
2700
2800
2900
3000
3100
3200
3300
3400
3500
3600
3700
3800
3900
4000
4100
4200
4300
4400
1.
2
3
W·H & M·L·H
1903
1 Spectrum of Radium Bromide.
2 Nitrogen : Band Spectrum.
3 Spark Spectrum of Radium.

Fig. 8

farther in the direction of the red. Within this point spectrum, certain spots were distinctly brighter, due, in all probability, to the presence of bright lines at those portions of the spectrum. "Encouraged by this preliminary observation, we hoped that it might be possible, by availing ourselves of the accumulative power of continuous photographic exposure, to obtain a record of the blue, violet, and ultra-violet regions of the spectrum, if the glow radiation extended so far." A small quartz spectroscope was employed; the solid radium bromide was placed at a distance of about a millimetre in front of the slit, which had to be wider ($\frac{1}{450}$ of an inch) than if a bright object were being photographed. (In the case of the spark "spectrum" of radium and the comparison spectrum of nitrogen, a slit of less than half this width was used.) With an exposure of twenty-four hours, faint traces of two lines were seen on the plate. By increasing the exposure to seventy-two hours, the negative reproduced in our Fig. 8 was obtained. (The reproduction is enlarged $2\frac{1}{2}$ times.) The spectrum consists of eight bright lines, and at least eight faint lines, with a faint indication of a continuous spectrum in the blue region, which does not come out in the reproduction. It was seen at once that the two very strong characteristic lines of the "spark" spectrum of radium in this part of the spectrum—*viz.*, 3814·5 and 3649·6—were not present on the plates. It was clear that the spectrum was unlike that of the radium molecule when excited by the electric spark. As soon as measures were taken, it was found that several of them agreed in position (within the uncertainty above-mentioned, *viz.*, ·0002) with the lines in the spectrum of helium, but not with the most characteristic helium lines in this part of the spectrum. In August the experiments were continued, as it was desired to ascertain the cause of the non-appearance of the strongest helium lines, mentioned by Rutherford and Soddy. It then became apparent that these lines were due, not to *helium*, but to nitrogen, with which they agreed exactly. "Nearly the whole of the ultra-violet radiations appear to come from nitrogen, and we think it best to refrain from any discussion at this moment. Have we to do with occluded or with atmospheric nitrogen?" In the Fig. 8 is first placed a scale of approximate wave-

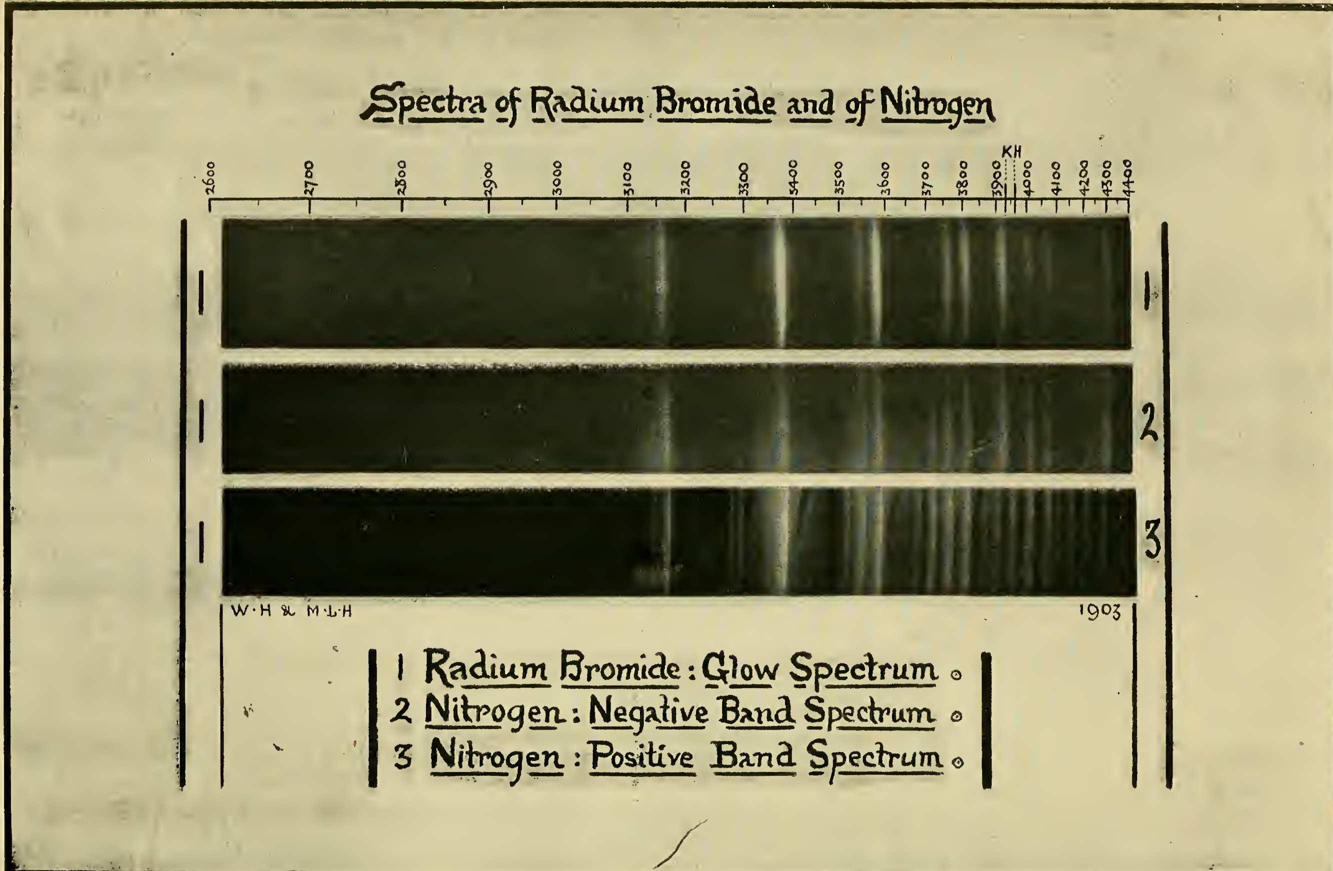
Spectra of Radium Bromide and of Nitrogen
2600
2700
2800
2900
3000
3100
3200
3300
3400
3500
3600
3700
3800
3900
K H
4000
4100
4200
4300
4400
1
2
3
W·H & M·L·H
1903
1 Radium Bromide : Glow Spectrum
2 Nitrogen : Negative Band Spectrum
3 Nitrogen : Positive Band Spectrum

FIG. 9.

lengths. Immediately below this is the reproduction of the "glow" spectrum of radium bromide; exposure, seventy-two hours; then follows the nitrogen spectrum. The identity of the two spectra seems complete. The third band is faint in the nitrogen spectrum on account of the absorption of the glass of the tube. Lastly, we have the "spark" spectrum of radium. Having received some samples of radium bromide from Buchler & Co., and from the Société Centrale des produits chimiques, the experiments were resumed in October, 1903, longer exposures being given. We reproduce here the result of 216 hours' exposure with the French bromide of radium, along with a negative and a positive discharge spectrum of nitrogen (*see* Fig. 9). Owing to the longer exposure, the radium bands come out with much greater distinctness; and in this case, also, the absolute identity of the lines of "glow" spectrum of radium and of nitrogen are shown to perfection. The result of these experiments, as far as concerns helium, was negative; which must not, of course, be interpreted as excluding the presence of helium, but only as showing that, if present, the conditions were not favourable to the appearance of its "spectrum." For many interesting details concerning these experiments, we must refer the reader to the "Proceedings of the Royal Society," Vol. 72, pp. 196 and 410.

27. We may now pass in conclusion to examine the arguments in favour of considering radium as belonging to the calcium-strontium and barium group of elements. Apart from the evidence afforded by its spectrum, and by the vapour density of its compounds, these are based upon what is known to chemists as Mendelëeff's "Periodic Law." Briefly stated this law expresses the fact that elements of similar general properties have atomic weights, specific gravities, and boiling points so related to one another that, taking the numbers expressing, say, the atomic weight of any three in regular ascending order, and dividing the sum of the two extremes by two, the result is *nearly* the number denoting the atomic weight of the central element. Any large departure from this result points either to the non-discovery of some element belonging to the group, to the presence of some undetected impurity, or to the mis-classification of some member of the group. So well

does this theory accord with facts, that the appearance of gaps in these numerical cycles, or periods, has led to the prediction, not only of the existence of numerous undiscovered elements, but of the probable properties which these elements would be found to possess, when discovered. These predictions have been very fully verified by the discovery in recent years of several elements; notably, of *gallium* and *germanicum*. As an example of our meaning, we will consider the case of three elements, of two well-known groups. Chlorine is a gas, having the atomic weight of 35·5; bromine is a liquid, its atomic weight 80; iodine is a solid, whose atomic weight is 127. Adding together the atomic weight numbers of the two extreme members of this group, and dividing the sum by two, we get, $\frac{35\cdot5+127}{2} = 81\cdot25$. Their vapour density is also related in the same manner, and their chemical activities are in inverse ratios to their atomic weights. Passing to the other group, we have sulphur 32, selenium 79·5, tellurium, 129; with specific gravities of 2, 4·5 and 6·25 respectively. Now $\frac{32+129}{2} = 80.5$, which is again pretty nearly the atomic weight of selenium. We might greatly extend these examples of such groups, but the above will suffice to call the reader's attention to the "periodicity" of the atomic weights of any given group of elements. Applying this rule to the case of radium, we should expect it to have an atomic weight of 234, since calcium's atomic weight is 40, and that of strontium is 137. Now $\frac{40+234}{2} = 137$. As a matter of fact Madame Curie gives 225, and Runge 257·8, as the atomic weight of radium. It is highly probable that it lies between these two, or 240 approximately.

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